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STATE OF THE ART LASER TECHNOLOGY IN DENTISTRY

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ABSTRACT

LASER technology has sneaked into our lifestyle through varied areas ranging from communications, entertainment, electronics, medicine and so on. Dentistry being an allied branch of medicine is no different. Although having wide application in the field dentistry there is relatively less knowledge amongst the practitioners pertaining to the physics and the working mechanisms behind its application. This review article will bring the specifications and reasons behind the use of LASER technology pertaining to Dentistry.

INTRODUCTION:

'LASER' is an acronym for Light Amplification by Stimulated Emission of Radiation. The physical principle of laser was developed from Einstein's theories in the early 1900s, and the first device was introduced in 1960 by Maiman. Since then, lasers have been used in many different areas in medicine and surgery.[1]

Laser light is a man-made single photon wavelength. Laser generates a very coherent (synchronous waves), monochromatic (a single wavelength), and collimated form (parallel rays) of light that is found nowhere else in nature. Lasers can concentrate light energy and exert a strong effect, targeting tissues at an energy level that is much lower than that of natural light. The characteristics of a laser depend on its wavelength. The different lasers used in dentistry are CO_2; Nd:YAG; Ho:YAG; Er:YAG; Er,Cr:YSGG; Nd:YAP; Ga As(diode); and argon.[2]

BASIC LASER SCIENCE:

Light

Light is a form of electromagnetic energy that behaves as a particle and a wave. The basic unit of this energy is called a photon. Laser light and ordinary light are significantly different.

Laser light is one specific color, a property called **monochromacity**; in dental applications that color may be visible or invisible. Laser light possesses two additional characteristics: collimation and coherency.

Collimation refers to the beam having specific spatial boundaries, which insures that there is a constant size and shape of the beam emitted from the laser cavity.

Coherency means that the light waves produced in the instrument are all the same. They are all in phase with one another and have identical wave shapes; that is, all the peaks and valleys are equivalent.

Amplification

Amplification is part of a process that occurs inside the laser. Identifying the components of a laser instrument is useful in understanding how light is produced.

An optical cavity is at the center of the device. The core of the cavity is comprised of chemical elements, molecules, or compounds and is called the active medium. Lasers are generically named for the material of the active medium, which can be a container of gas, a crystal, or a solid-state semiconductor. There are two gaseous active medium lasers used in dentistry: argon and CO_2. The remainder that are available are solid-state semiconductor wafers made with multiple layers of metals such as gallium, aluminum, indium, and arsenic or solid rods of garnet crystal grown with various combinations of yttrium, aluminum, scandium and gallium and then doped with the elements chromium, neodymium, or erbium. There are two mirrors, one at each end of the optical cavity, placed parallel to each other. Surrounding this core is an excitation source, either a flash lamp strobe device or an electrical coil, which provides the energy into the active medium. A cooling system, focusing lenses, and other controls complete the mechanical components.

Stimulated emission

The term "stimulated emission" has its basis in the quantum theory of physics. A quantum, the smallest unit of energy, is absorbed by the electrons of an atom or molecule, causing a brief excitation; then a quantum is released by a process called spontaneous emission. This quantum emission, also termed a photon, can be of various wavelengths because there are several electron orbits with different energy levels in an atom. Albert Einstein theorized that an additional quantum of energy travelling in the field of the excited atom that has the same excitation energy level would result in a release of two quanta, a phenomenon he termed stimulated emission. This process would occur just before the atom could undergo spontaneous emission. The energy is emitted or radiated, as two identical photons, traveling as a coherent wave.

These photons are able to energize more atoms, which further emit additional identical photons, stimulating more surrounding atoms. If the conditions are right, a population inversion occurs, meaning that a majority of the atoms of the active medium are in the elevated rather than the resting state. There must be a constant supply of energy called a pumping mechanism, to maintain this excitation.

The mirrors at each end of the active medium reflect these photons back and forth to allow further stimulated emission and successive passes through the active medium increase the power of the photon beam: This is the process of amplification. There is some heat-generated in the process and the optical cavity must be cooled. The parallelism of the mirrors insures that the light is collimated. One of the mirrors is selectively transmissive, allowing light of sufficient energy to exit the optical cavity.

Radiation

Radiation refers to the light waves produced by the laser as a specific form of electromagnetic energy. All available dental laser devices have emission wavelengths of approximately 0.5 µm (or 500 nm) to 10.6 µm (or 10,600 nm). They are therefore within the visible or the invisible infrared nonionizing portion of the electromagnetic spectrum and emit thermal radiation. The dividing line between the ionizing (i.e., the cellular DNA mutagenic portion of the spectrum) and the nonionizing portion is on the junction of ultraviolet and visible violet light.

In summary, a laser consists of a lasing medium contained within an optical cavity, with an external energy source to maintain a population inversion so that stimulated emission of a specific wavelength can occur, producing a monochromatic, collimated and coherent beam of light.[3]

LASER DELIVERY SYSTEMS:

The coherent, collimated beam of laser light should be delivered to the target tissue in a manner that is ergonomic and precise. There are two delivery systems used.

- One is a flexible hollow waveguide or tube that has an interior mirror finish. The laser energy is reflected along this tube and exits through a handpiece at the surgical end with the beam striking the tissue in a noncontact fashion. An accessory tip of sapphire or hollow metal can be connected to the end of the waveguide for contact with the surgical site.
- The second delivery system is a glass fiber optic cable. This cable can be more pliant than the waveguide, has a corresponding decrease in weight and resistance to movement, and is usually smaller in diameter (some soft tissue lasers have optic fibers with sizes ranging from 200-600 µm). Although the glass component is encased in a resilient sheath, it can be fragile and cannot be bent into a sharp angle. The fiber fits snugly into a handpiece with the bare end protruding or in the case of the erbium family of lasers, with an attached

sapphire or quartz tip. This fiber system can be used in contact or noncontact mode. Most of the time it is used in contact fashion, directly touching the surgical site.

All the invisible dental lasers are equipped with a separate aiming beam, which can be laser or conventional light. The aiming beam is delivered coaxially along the fiber or waveguide and shows the operator the spot where the laser energy will be focused.

In either modality, lenses within the laser instrument focus the beam. With the hollow waveguide, there is a spot of a specific diameter where the beam is in sharp focus and where the energy is the greatest. That spot, called the focal point; should be used for incisional and excisional surgery. At a small divergent distance, the laser light can cover a wider area, which is useful in achieving hemostasis. At a greater distance, the beam loses its effectiveness because the energy dissipates with a proportional decrease in power density.

Lasers with shorter emission wavelengths, such as argon, diode, and Nd:YAG, can be designed with small, flexible glass fibers. The Er,Cr:YSGG and Er:YAG devices present challenges to fiber manufacturing because their wavelengths are large and do not easily fit into the crystalline molecules of the conducting glass. The largest dental wavelength, CO_2, is beyond the transmission window of current fiber optic technology and has to be conducted in a hollow tube.[3]

LASER EMISSION MODES:
The dental laser device can emit the light energy in two modalities as a function of time, constant on or pulsed on and off. The pulsed lasers can be further divided into two distinctive ways in which the energy is delivered to the target tissue[4]. Thus, three different emission modes are described.

- The first is continuous wave, meaning that the beam is emitted at only one power level for as long as the operator depresses the foot switch.
- The second is termed gated-pulse mode, meaning that there are periodic alternations of the laser energy, much like a blinking light. This mode is achieved by the opening and closing of a mechanical shutter in front of the beam path of a continuous wave emission.
- The third mode is termed free-running pulsed mode, sometimes referred to as "true pulsed". This emission is unique in that large peak energies of laser light are emitted for a short time span, usually in microseconds, followed by a relatively long time in which the laser is off. Free-running pulsed devices have a rapidly strobing flashlamp that pumps the active medium. The timing of this emission is computer controlled, not mechanically controlled as in a gated pulse device.

Medical and scientific laser instruments are available whose pulse durations are in the nanosecond (one billionth of a second) and pico-second (one trillionth of a second) and smaller range. These can generate tremendous peak powers, but the calculated pulse energies are small, allowing increased surgical precision.

The important principle of any laser emission mode is that the light energy strikes the tissue for a certain length of time, producing a thermal interaction. If the laser is in a pulsed mode, the targeted tissue has time to cool before the next pulse of laser energy is emitted. In continuous wave mode, the operator must cease the laser emission manually so that thermal relaxation of the tissue may occur.[3]

LASER-TISSUE INTERACTION:
Laser light can have four different interactions with the target tissue, depending on the optical properties of that tissue. Dental structures have complex composition, and these four phenomena occur together in some degree relative to each other[5].

ABSORPTION:- The first and most desired interaction is the ***absorption*** of the laser energy by the intended tissue. The amount of energy that is absorbed by the tissue depends on the tissue characteristics, such as pigmentation and water content, and on the laser wavelength and emission mode. Tissue compounds called chormophores preferentially absorb certain wavelengths. Hemoglobin, the molecule that transports oxygen to tissue, reflects red wavelengths, imparting color to arterial blood. It therefore is strongly absorbed by blue and green wavelengths. Venous blood, containing less oxygen, absorbs more red light and appears darker. The pigment melanin, which imparts color to skin, is strongly absorbed by short wavelengths. Water, the universally present molecule, has varying degrees of absorption by different wavelengths.

Dental structures have different amounts of water content by weight. A ranking from lowest to highest would show enamel (with 2% to 3%), dentin, bone, calculus, caries, and soft tissue (at about 70%). Hydroxyapatite is the chief crystalline component of dental hard tissues and has a wide range of absorption depending on the wavelength.

In general, the shorter wavelengths (from about 500-1000 nm) are readily absorbed in pigmented tissue and blood elements. Argon is highly attenuated by hemoglobin. Diode and Nd:YAG have a high affinity for melanin and less interaction with hemoglobin. The longer wavelengths are more interactive with water and hydroxyapatite. The largest absorption peak for water is just below 3000 nm, which is at the Er:YAG wavelength. Erbium is also well absorbed by hydroxyapatite. CO_2 at 10,600 nm is well absorbed by water and has the greatest affinity for tooth structure.

TRANSMISSION:- The second effect is ***transmission*** of the laser energy directly through the tissue with no effect on the target tissue, the inverse of absorption. This effect is highly dependent on the wavelength of laser light. Water, for example, is relatively transparent to the shorter wavelengths like Argon, Diode, and Nd:YAG, whereas tissue fluids readily absorb the Erbium family and CO_2 at the outer surface, so there is little energy transmitted to adjacent tissues. In general, the erbium family acts mainly on the surface, with an absorption depth of approximately 0.01 mm, whereas the 800-nm diodes are transmitted through the tissue to depths up to 100 mm, a factor of 10,000. As another example, the diode and Nd:YAG lasers are transmitted through the lens, iris, and cornea of the eye and are absorbed on the retina.

REFLECTION:- The third effect is ***reflection***, which is the beam redirecting itself off of the surface, having no effect on the target tissue. A caries-detecting laser device uses the reflected light to measure the degree of sound tooth structure. The reflected light could maintain its collimation in a narrow beam or become more diffuse.

SCATTERING:- The fourth effect is a ***scattering*** of the laser light, weakening the intended energy and possibly producing no useful biologic effect. Scattering of the laser beam could cause heat transfer to the tissue adjacent to the surgical site, and unwanted damage could occur. However a beam deflected in different directions is useful in facilitating the curing of composite resin or in covering a broad area.

Absorption of the laser light by the target tissue is the primary and beneficial effect of laser energy. The goal of dental laser surgery is to optimize these photobiologic effects. Using the photothermal conversion of energy, incisions and excisions with accompanying precision and hemostasis are some of the many advantages of laser devices. There are photochemical effects from laser light that can stimulate chemical reactions (eg, the curing of composite resin) and breaking of chemical bonds (eg, using photosensitized drugs exposed to laser light to destroy tumor cells, a process called photodynamic therapy). A laser can be used with powers well below the surgical threshold for biostimulation, producing more rapid wound healing, pain relief, increased collagen growth, and a general anti-inflammatory effect. The pulse of laser energy into a crystalline structure can produce an audible shock wave, which could explode or pulverize the tissue with mechanical energy. This is an example of the photoacoustic effect of laser light.

To summarize the tissue interaction effect of a particular machine, several factors must be considered. Each laser has common internal parts but different delivery systems and emission modes. The laser wavelength affects certain components of the target tissue; the water content, the color of the tissue, and the chemical composition are all inter-related. The diameter of the laser beam, whether delivered in contact or noncontact with the tissue, creates a certain energy density — the smaller the beam, the greater the energy density. For example, a beam diameter of 200 μm has over twice as much energy density as a beam diameter of 300 μm. The result of using the smaller fiber is greatly increased thermal transfer from the laser to the tissue and a corresponding increase in absorption of heat in that smaller area. The amount of time that the beam is allowed to strike the target tissue affects the rate of tissue temperature rise. That time can be regulated by the repetition rate of the pulsed laser emission mode as well. The amount of cooling of the tissue by the use of a water or air spray also affects the rate of vaporization.[3]

CLASSIFICATION OF LASERS:
There are many different types of lasers. The laser medium can be a solid, gas, liquid or semiconductor[6].

I. Based on type of lasing material employed

- **Solid-State Lasers** have lasing material distributed in a sold matrix (such as the Ruby or Neodymium:Yttrium-Aluminum Garnet "YAG" lasers). The Neodymium:YAG laser emits infrared light at 1,064 nanometers (nm).
- **Gas Lasers** (Helium and Helium-Neon, HeNe, are the most common gas lasers) have a primary output of visible red light. CO_2 lasers emit energy in the far infrared, and are used for cutting hard materials.
- **Excimer Lasers (**the name is derived from the terms excited and dimers) use reactive gases, such as chlorine and fluorine, mixed with inert gases such as Argon, Krypton or Xenon. When electrically stimulated, a pseudo molecule (dimer) is produced. When lased, the dimer produces light in the ultra violet range.
- **Dye Lasers** use complex organic dyes, such as rhodamine 6G, in liquid solution or suspension as lasing media. They are tunable over a broad range of wavelengths.

- **Semiconductor Lasers** sometimes called diode lasers, are not solid-state lasers. These electronic devices are generally very small and use low power. They may be built into larger arrays, such as the writing source in some laser printers or CD players.

II. Based on application
- Soft Tissue Laser
  eg: Argon, CO_2, Diode, Nd:YAG.
- Hard Tissue Laser
  eg: Er:YAG
- Resin Curing Laser
  eg: Argon

III. Mode of action
- Contact mode (focused or defocused)
  eg: Ho:YAG, Nd:YAG
- Non-contact mode (focused or defocused)
  eg: CO_2

IV. Based on Level of energy emission:
a. Soft lasers (low level energy): A thermal low energy lasers emitted at wave length, which are supposed to stimulate cellular activity. Example: He-Neon; Ga-Arsenide.

b. Hard lasers (High level energy): Thermal lasers emitted at wavelength in the visible infra red and UV range. Example: Er:YAG laser, Nd:YAG laser.

V. Based on radiant energy generation:
1. Continuous wave or continuous form (CW)
2. Discreet or single pulses
3. Multiple timed pulses (Pulse modes)

VI. Based on wavelength and medium:

Argon fluoride (UV)	193
Krypton fluoride (UV)	248
Nitrogen (UV)	337
Argon (Blue)	488
Argon (Green)	514
Helium Neon (Green)	543
Helium Neon (red)	633
Rhodamine 6G dye (tunable)	570-650
Nd:YAG (NIR)	1064
Carbon dioxide (FIR)	10600
Er:YAG (NIR)	2940
Ho:YAG	2000-2200
Er,Cr:YSGG	2780

BIOLOGIC RATIONALE FOR LASER USE IN DENTISTRY:
Optimal therapeutic effects result when the wavelength best absorbed by the target tissue is selected for use; however, the choice of the best laser for a certain procedure depends on much more than just matching emission spectra of lasers to absorption spectra of tissues[7]. The uses of lasers in the various disciplines of dentistry are listed below.

Periodontology[8]:
- Initial (nonsurgical) pocket therapy
- Nonosseous gingival surgery
  - Frenectomy
  - Gingivectomy
  - Soft tissue grafts
- Periodontal regeneration surgery
  - De-epithelization
  - Removal of granulomatous tissue
  - Osseous recontouring

Fixed prosthetics / cosmetics:
- Crown lengthening / soft tissue management around abutments
- Osseous crown lengthening
- Troughing
- Formation of ovate pontic sites
- Altered passive eruption management
- Modification of soft tissue around laminates
- Bleaching

Implantology[8]:
- Second-stage recovery
- Peri-implantitis

Removable prosthetics:
- Epulis fissurata
- Denture stomatitis
- Residual ridge modification
  - Tuberosity reduction
  - Torus reduction
  - Soft tissue modification

Pediatrics / Orthodontics:
- Exposure of teeth
- Soft tissue management of orthodontic patients

Oral surgery / Oral medicine / Oral pathology:
- Biopsy
- Operculectomy
- Apicoectomy
- Oral soft tissue pathologies

Operative dentistry[9]:
- Caries ablation
- Cavity preparation
- Dentinal hypersensitivity
- Root canal therapy

Safety precautions to be practiced:
1. Caution before and during irradiation[10]
- Use of glasses for eye protection (patient, operator and assistants).
- Inadvertent radiation (action in noncontact mode).
- Protection of patient's eyes, throat, and oral tissues outside the target site.
- Reflection from shiny metal surfaces.
- Adequate high speed evacuation to capture the laser plume.

2. Risk of excessive tissue destruction by direct ablation and thermal side-effects[10]
- Destruction of the attachment apparatus at the bottom of pockets
- Excessive ablation of root surfaces and gingival tissue within periodontal pockets
- Thermal injury to the root surface, gingival tissue, pulp and bone tissue

3. Problems of laser systems[10]
- Further development of a new laser system
- Development and improvement of contact probes suitable for periodontal treatment
- Reduction of high cost of laser apparatus

4. Fire and explosion hazards:[10]
Fire hazards associated with class IV lasers take many forms. Proper procedure to minimize this kind of problem should include the following:
- Use only wet or fire-retardant materials in the operative field.
- Use only noncombustible anesthetic agents.
- Avoid alcohol-based topical anesthetic.

- Avoid alcohol-moistened gauze while firing the laser.
- Protect tissues adjacent to the surgical site.
- Know location and operation of the nearest fire extinguisher.
- Store highly combustible or explosive materials outside the nominal hazardous zone.
- Adhere to the ANSI directive: "Nitrous oxide supports combustion and should not be used during laser surgery".

STERILIZATION AND INFECTION CONTROL:

Steam sterilization is the standard of care. The small flexible optic fibers, handpieces, or tips must be steam sterilized in separate sterilization pouches after each use. They should be kept in the sterilization pouch until ready for use. It is essential that when using fiber-optically delivered lasers, the port (connecting) end remains clean and oil-free. Therefore, never run the fiber in a sterilizer cycle alongside a high-speed turbine with lubricant. If an instrument was used to cleave or recleave a fiber during or after a procedure, then it also must be steam sterilized[11].

The protective housing around the laser, including the control panel and articulating arm (if applicable) should receive the spray disinfectant, decontamination method, as do the dental cart and counter tops. Some delivery system components such as the large-diameter erbium fiber-optic cable are not designed for steam sterilization and must be disinfected in this way[11].

CONCLUSION:

LASER today is in use almost everywhere and Dentistry is no exception. With the advent of Laser technology, it has taken special place in the field of dentistry. Dental schools are into lot of research work pertaining to Laser application for dental treatment. Laser is available in various wavelengths which indeed has different indications. The clinician should know basics of Laser wavelength in terms of physics, tissue interactions and its indications for use. There is always a need to explore more of its applications and reliability upon dental treatment before it can be considered as sole treatment option according to its use.

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